Excess heat potentials

Urban Persson
Halmstad University (SE)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 767429.

Excess heat potentials

- Main contributors
  - Halmstad University (SE)
    - Urban Persson
    - Helge Averfalk
    - Sven Werner
  - Europa-Universität Flensburg (DE)
    - Bernd Möller
    - Eva Wiechers
  - Aalborg University (DK)
    - Lars Grundahl
    - Rasmus Søgaard Lund
    - Brian Vad Mathiesen
    - Henrik Lund

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Excess heat potentials

What do we mean by excess heat?

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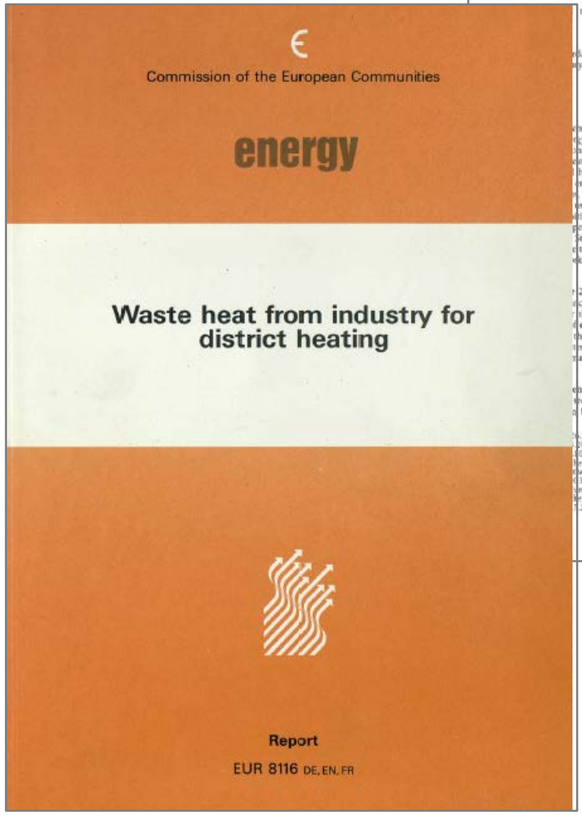
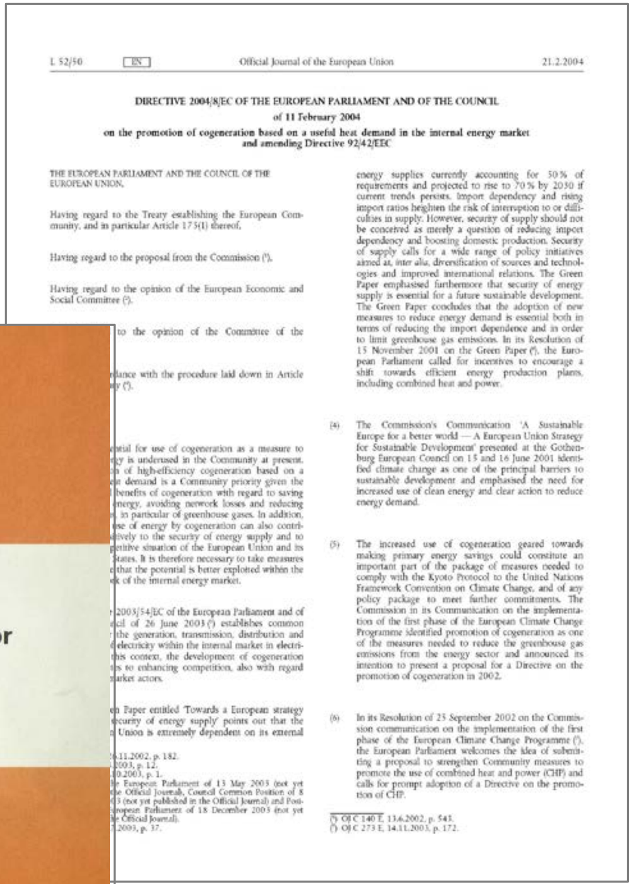
Excess heat potentials

- By source categories:
  - Conventional sources
    - Rejected heat in thermal power generation processes not absorbed as electricity
    - Rejected heat in industrial processes not added or maintained in industrial products
  - Unconventional sources
    - Rejected heat from cooling systems in buildings, data centres, food production and retail facilities etc.
    - Heat available in metro station ventilation exhaust air and sewage waste-water
    - Electric transformers, bakeries...




L 52/50 EN Official Journal of the European Union 21.2.2004

DIRECTIVE 2004/8/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 11 February 2004

on the promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EEC

THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION,

Early recognitions of excess heat in EU:
Left: Energy: Waste heat from industry to district heating. Report EUR 8116. European Commission, Luxembourg, 1982.
Right: Directive 2004/8/EC on the promotion of cogeneration based on a useful heat demand in the internal energy market... European Parliament and the Council; 2004.

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Excess heat potentials

What do we mean by excess heat recovery?

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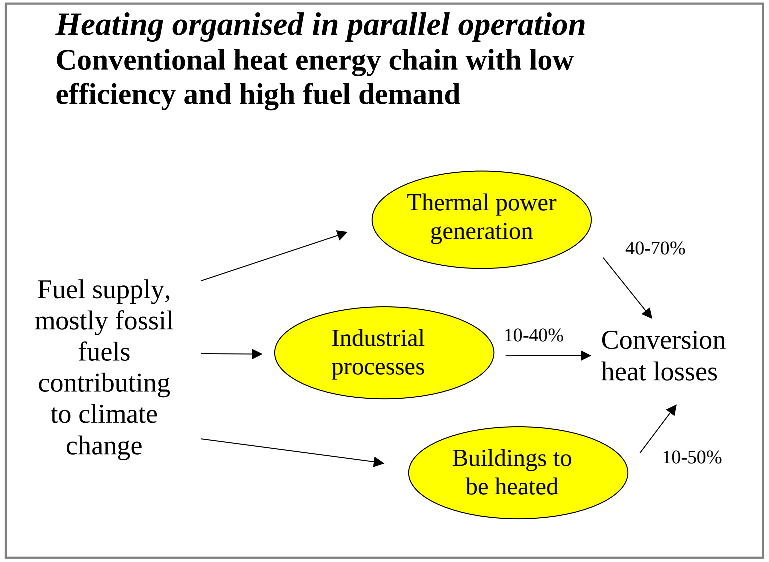
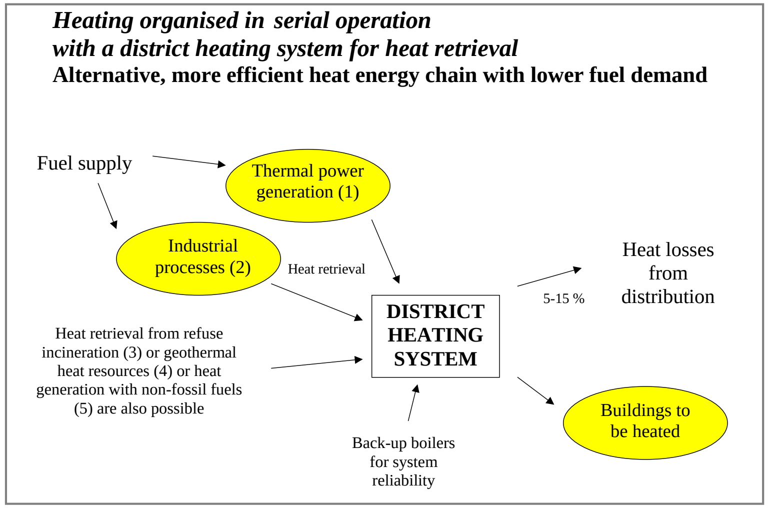
Excess heat potentials

- Sequential energy supply:
  - Parallel supply structures
    - The fossil economy has shaped parallel supply structures where each activity converts primary energy separately and often with only partial use of the fuel energy content
  - Serial supply structures
    - Feeding subsequent energy demanding processes with excess energy from a previous step, which reduces primary energy demands for the sum of processes engaged in the synergy chain (energy cascading)
  - Structural energy efficiency measure!

Source: Persson U, Werner S. District heating in sequential energy supply. Applied Energy. 2012;95:123-31.





Source: Werner S. Unpublished.

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Excess heat potentials

How can excess heat be utilised?

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Excess heat potentials

- Different uses:
  - On-site
    - Direct internal use
      - Process optimisation
      - Space heating
      - Hot water preparation
    - Industrial symbiosis
  - Distribution
    - District heating systems
      - Space heating
      - Hot water preparation
      - Absorption cooling
    - District energy grids
      - Thermal systems

Rotary kiln (left) and plate heat exchanger (right) for recovery of flue gas excess heat to district heating at Portland Cement in Aalborg, Denmark. Photos: U. Persson.

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Excess heat potentials

Barriers?

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Excess heat potentials

- Several, some examples:
  - Invisibility
    - Excess heat infrastructures and components seldom directly visible
    - Recovered energy is not allowed in energy statistics templates
  - Complexity
    - Multiple actor involvement
      - Local initiative and communication
      - Collaboration agreements
      - Allocation of synergy benefits
    - Dependency on district heating deployment for large-scale utilisation
      - Infrastructure investments
    - Overview planning perspective…

Wind turbines at off-shore wind park Lillgrund in Malmö, Sweden (left) and section of absorption cooling installation at Halmstad University, Sweden (right). Photos: U. Persson.

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Overview

- Excess heat potentials
  - The work of HRE
    - Conventional excess heat sources
    - Regional quantification
    - Allocation mapping
  - ReUseHeat – Extending the work of HRE
    - Unconventional excess heat sources
    - Accessible and available excess heat
    - Current district heating city areas
    - Spatial allocation
  - Results and conclusions
    - Potentials summary
    - Challenges and drivers
    - Recommendations

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The work of HRE

- Conventional excess heat sources
  - Input data
    - CO_2 emission data on facility level
    - Geographical coordinates
    - Standard CO_2 emission factors by fuel type
    - Main sector fuel use by Member State
    - Default recovery efficiencies by main sectors
  - Calculations
    - Primary energy supply at facility level
    - Theoretical excess heat potentials
  - Spatial analytics
    - Locations and distances
    - Allocation mapping

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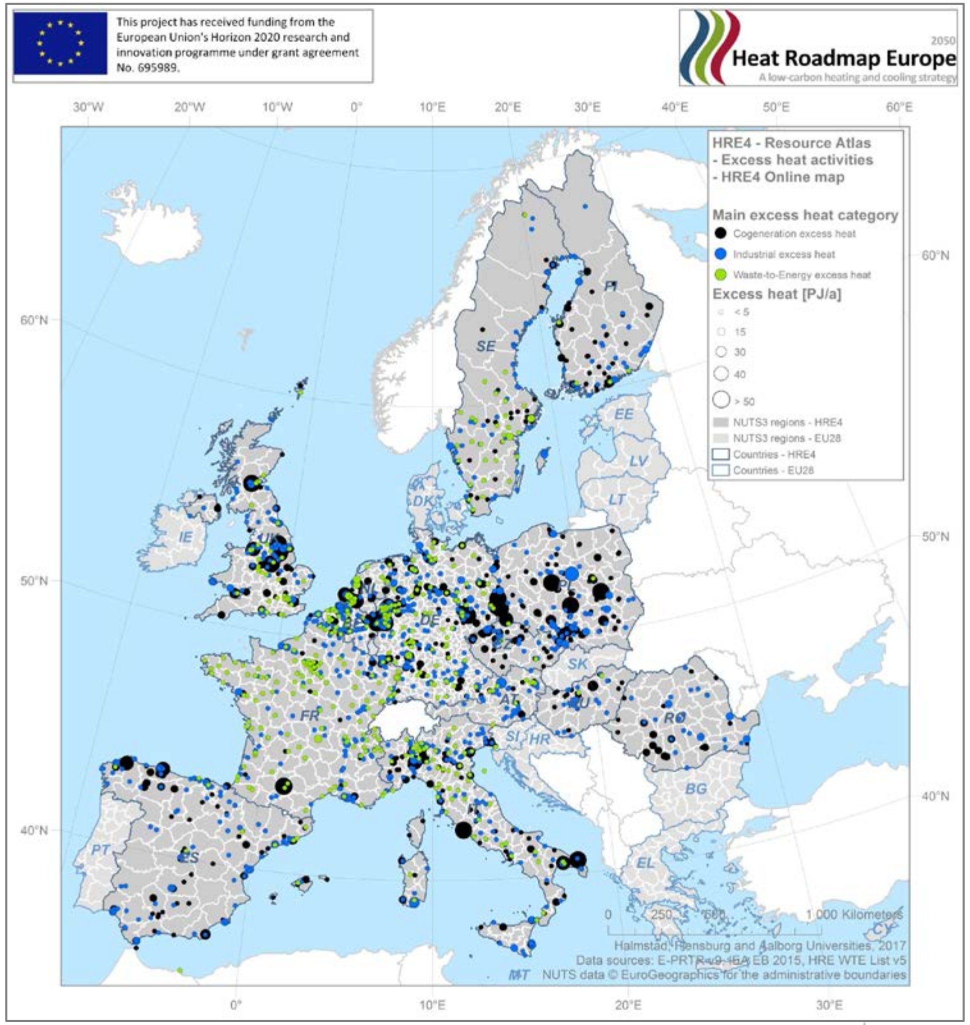
The work of HRE

- Conventional excess heat sources
  - Cogeneration (Thermal power plants)
    - Main activities
    - Auto-producers
  - Industrial
    - Chemical and petrochemical
    - Food and tobacco
    - Fuel supply and refineries
    - Iron and steel
    - Mining and quarrying
    - Non-ferrous metals
    - Non-metallic minerals
    - Paper, pulp and printing
  - Waste-to-Energy (Incineration plants)

2188 HRE4 facilities:
800 Cogeneration
978 Industrial
410 Waste-to-Energy

2450 EU28 facilities:
924 Cogeneration
1077 Industrial
449 Waste-to-Energy



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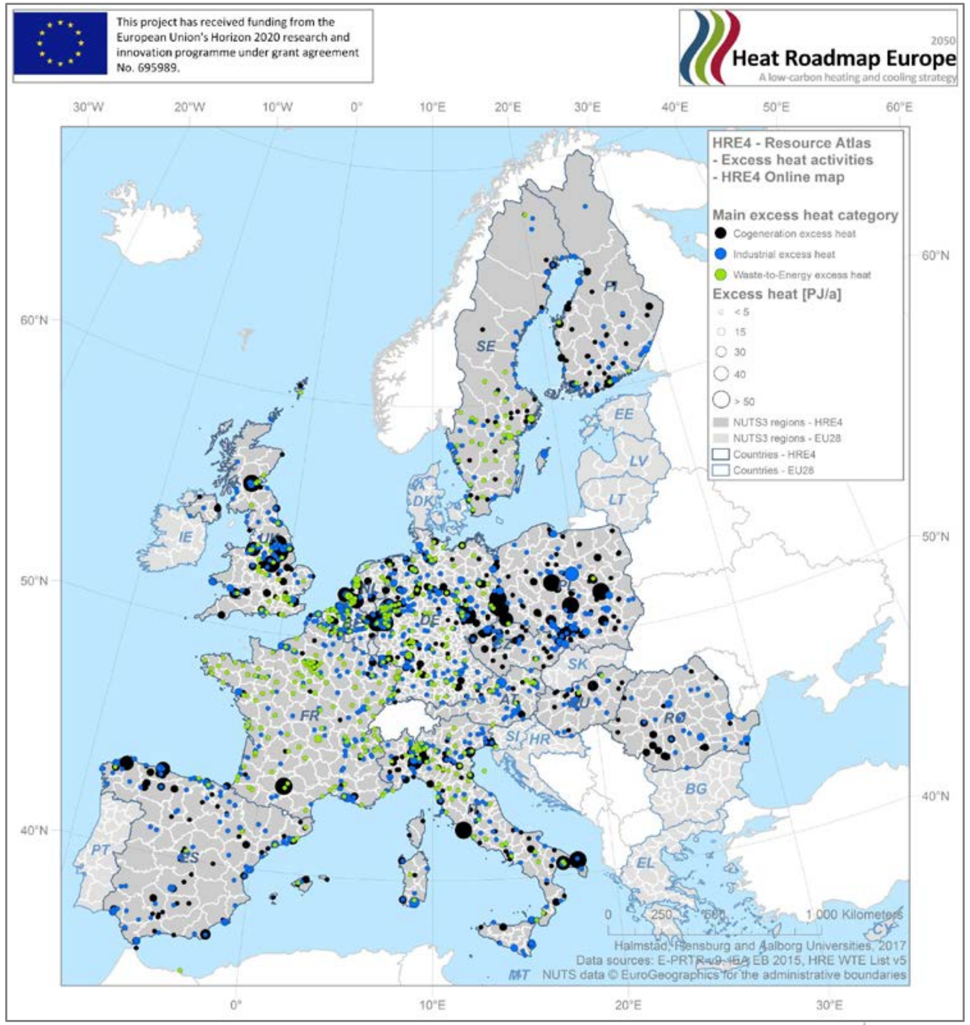
The work of HRE

- Conventional excess heat sources
  - Default recovery efficiencies
    - Standard conversion heat losses
    - Maximum theoretical potential

Main activity sector category	η_{heat}
Thermal Power – Main Activity	50%
Thermal Power – Auto-producer	60%
Thermal Power – Waste-to-Energy	60%
Fuel supply and refineries	50%
Chemical and petrochemical	25%
Iron and steel	25%
Non-ferrous metals	25%
Non-metallic minerals	25%
Paper, pulp and printing	25%
Food and beverage	10%

Source: Persson, U., Möller, B., Werner, S. (2014). Heat Roadmap Europe: Identifying strategic heat synergy regions. Energy Policy 74(0): 663-681.



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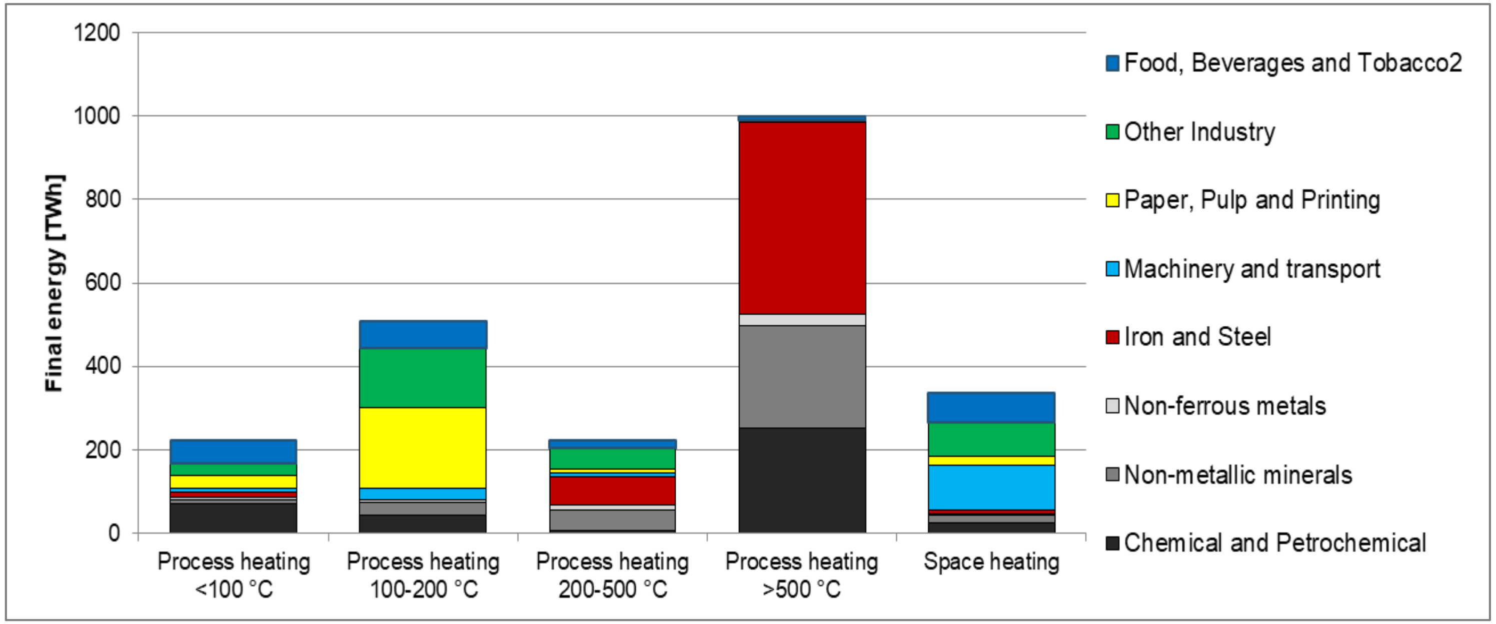
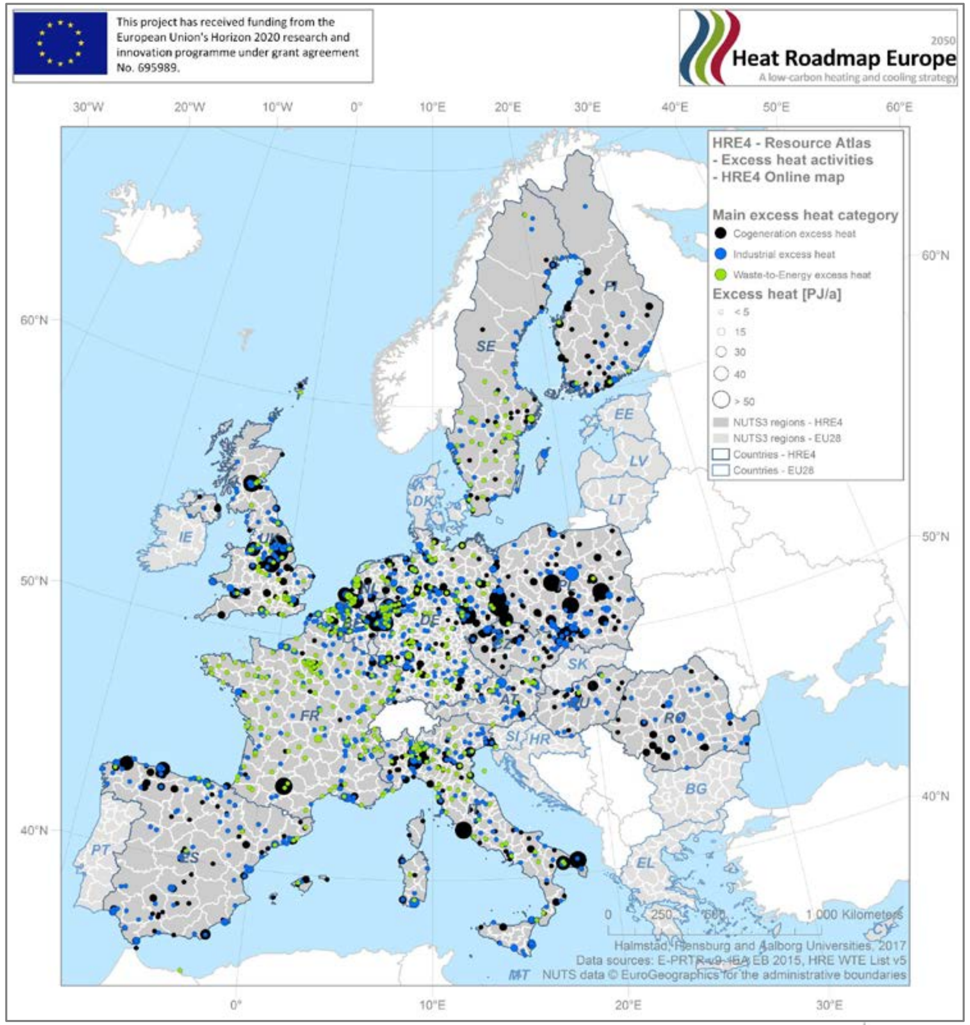
The work of HRE

- Conventional excess heat sources
  - Temperature levels (Industrial)



Majority of industrial final heat demands above 100 °C.

Source: Fleiter T, Elsland R, Rehfeldt M, Steinbach J, Reiter U, Catenazzi G, et al. 2017. Deliverable 3.1: Profile of heating and cooling demand in 2015 - Data Annex [HRE4-Exchange-Template-WP3_v22b_website.xlsx]. Heat Roadmap Europe 2050, A low-carbon heating and cooling strategy.



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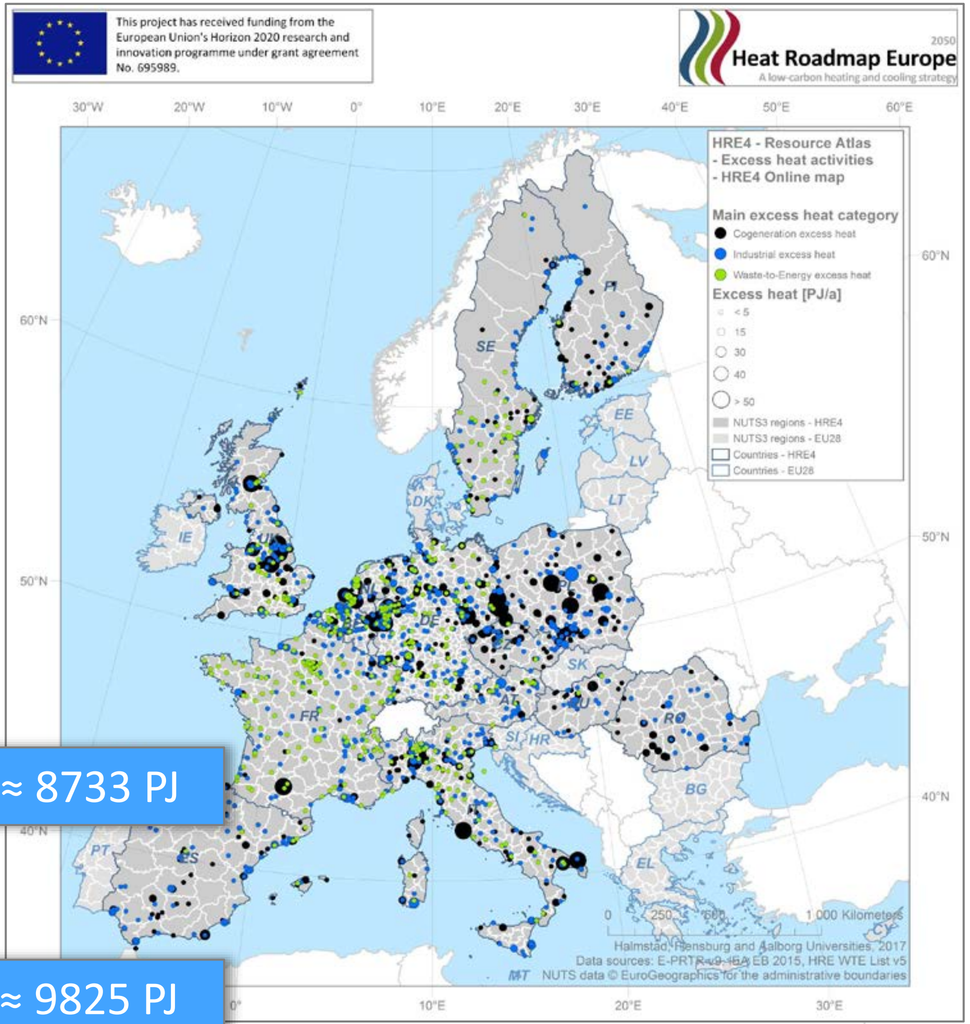
The work of HRE

- Conventional excess heat sources
  - Theoretical potential

Table 3.2. NUTS3 regions (N3R) in the 14 HRE4 MS´s, all in study (left), all with excess heat activities in operation (right), by population (P), heat demand in residential and service sectors (HD), primary energy supply (PES), excess heat (EH), and references to corresponding EU28 totals. Excess heat specified by sectors: Thermal Power (TP), Industrial (IND), and Waste-to-Energy (WTE). Energy volumes in TWh/a. Population in millions

	HRE4 14 MS´s			HRE4 14 MS´s with excess heat ratio value > 0							
MS	**N3R**	**P**	**HD**	**N3R**	**P**	**HD**	**PES**	**EH**	***TP***	***IND***	***WTE***
AT	35	8.6	64.5	20	6.4	48.1	112.3	38.1	9.0	24.2	4.9
BE	44	11.3	90.1	31	9.8	78.4	182.6	68.2	29.2	35.1	4.0
CZ	14	10.5	65.9	14	10.5	65.9	207.0	90.3	73.9	15.1	1.3
DE	402	81.2	670.4	203	51.5	424.8	1575.4	686.2	492.4	148.1	45.7
ES	52[a]	44.3	130.8	46	42.7	125.7	420.2	174.2	108.8	62.5	2.8
FI	19	5.5	62.9	18	5.4	62.6	146.7	57.9	35.5	22.0	0.4
FR	96[b]	64.3	420.6	79	59.2	388.6	421.5	156.2	50.5	79.0	26.7
HU	20	9.9	58.3	14	8.0	47.5	71.2	29.3	20.0	8.6	0.7
IT	110	60.8	354.7	91	55.7	327.8	582.9	258.7	179.6	69.3	9.7
NL	40	16.9	118.1	25	11.8	82.2	345.3	155.3	99.5	40.9	14.9
PL	72	38.0	182.7	57	31.2	149.9	641.8	289.0	242.2	46.7	0.0
RO	42	19.9	50.8	27	14.4	36.6	138.2	56.7	[illegible]	[illegible]	[illegible]
SE	21	9.7	82.3	21	9.7	82.3	142.7	51.9	[illegible]	[illegible]	[illegible]
UK	173	64.9	378.6	86	34.9	204.6	700.5	313.8	[illegible]	[illegible]	[illegible]
HRE4	**1140**	**445.7**	**2730.8**	**732**	**351.2**	**2124.9**	**5688.3**	**2425.8**	*1630.1*	*657.5*	*138.2*
Share [%]	**100**	**100**	**100**	**64**	**79**	**78**	**100**	**100**	*67*	*27*	*6*
EU28 (Ref.)	1328[c]	503.7	2977.4	833	393.2	2316.7	6404.6	2729.5	1853.8	731.5	144.2
Share of Ref.	86	88	92	88	89	92	89	89	88	90	96



HRE4: 2425.8 TWh ≈ 8733 PJ

EU28: 2729.5 TWh ≈ 9825 PJ

Maximum theoretical potentials!

Source: Persson U, Möller B, Wiechers E. Methodologies and assumptions used in the mapping. Deliverable 2.3: methodology and assumptions used in the mapping. August 2017. Heat Roadmap Europe 2050, A low-carbon heating and cooling strategy.

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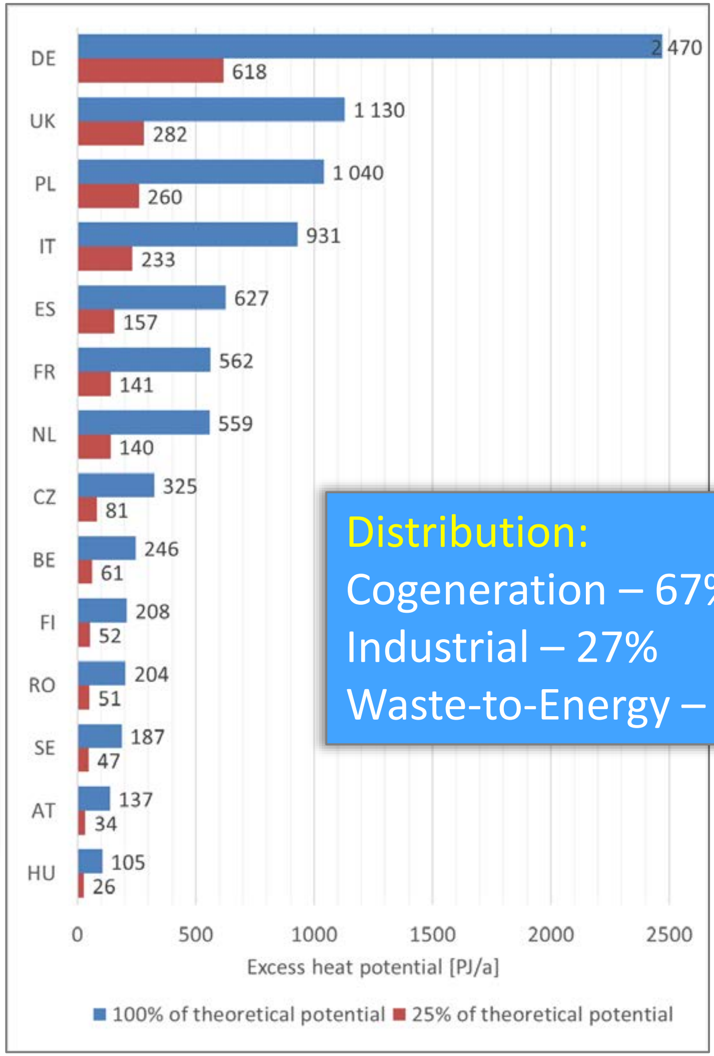
The work of HRE

- Conventional excess heat sources
    - Theoretical potential

Main sector	Count of Facilities	Primary energy supply [PJ/a]	Excess heat (100%) [PJ/a]	Excess heat (25%) [PJ/a]
Chemical and petrochemical	202	1590	397	99
Food and tobacco	47	139	14	3
Fuel supply and refineries	90	1645	822	206
Iron and steel	108	1819	455	114
Mining and quarrying	21	109	11	3
Non-ferrous metals	31	126	31	8
Non-metallic minerals	324	1742	436	109
Paper, pulp and printing	155	802	201	50
Thermal Power - AP	37	301	180	45
Thermal Power - MA	762	11376	5688	1422
Thermal Power - WtE	411	829	498	124
Grand Total	**2188**	**20478**	**8733**	**2183**

EU28 potential interval: ~2.5 EJ to ~9.8 EJ



Distribution:
Cogeneration – 67%
Industrial – 27%
Waste-to-Energy – 6%

Source: Persson U, Möller B, Wiechers E, Grundahl L. Map of the heat synergy regions and the cost to expand district heating and cooling in all 14 MS. Accessing the outputs of D2.2. Deliverable 2.2. Heat Roadmap Europe 2050, A low-carbon heating and cooling strategy. 2017.

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The work of HRE

- Regional quantification

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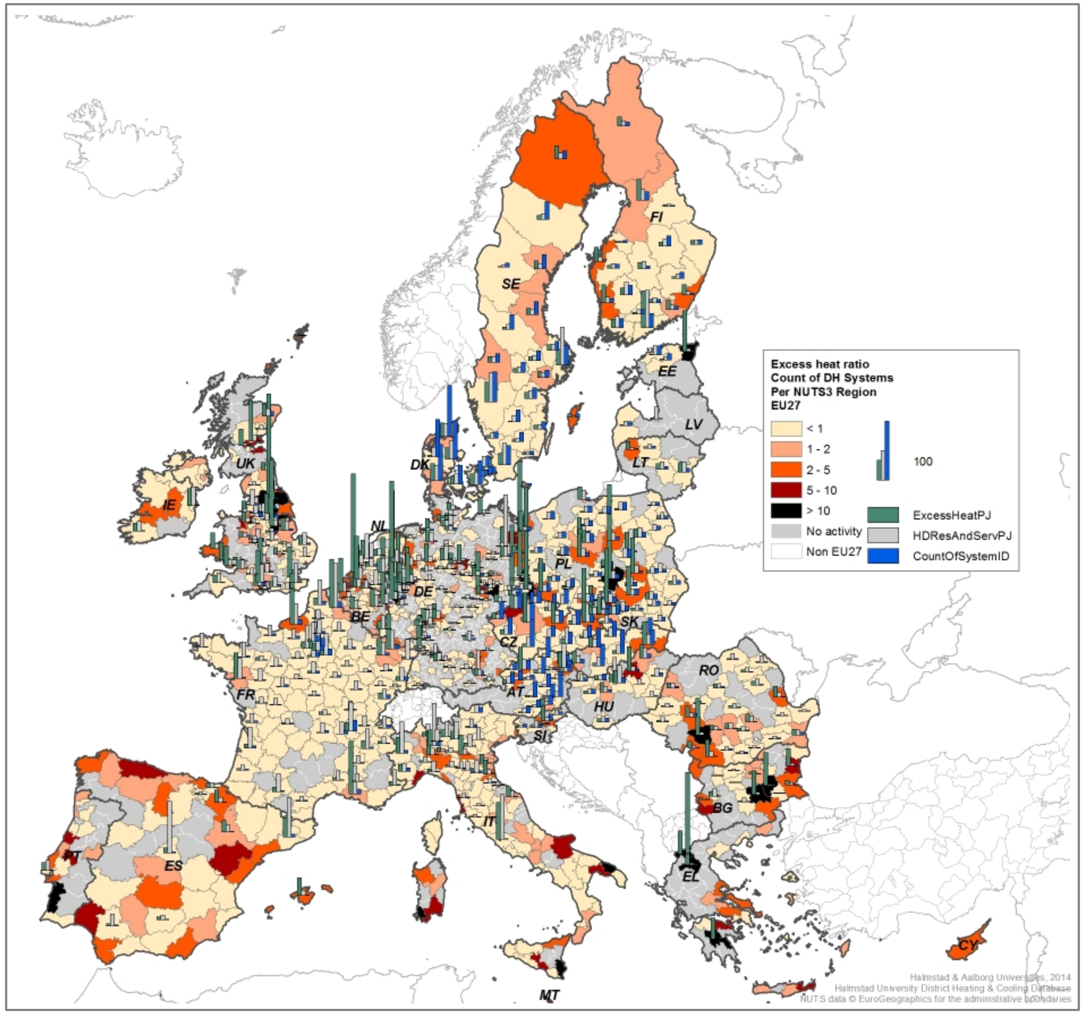
The work of HRE

- Regional quantification
  - NUTS3 regions
    - Building heat demands
    - Excess heat activities (Conventional)
    - District heating systems
  - Spatial analytics
    - Towards allocation mapping…
    - Excess heat ratio
      - Excess heat by heat demands
    - Indicative



Source: Persson, U., Möller, B., Werner, S. (2014). Heat Roadmap Europe: Identifying strategic heat synergy regions. Energy Policy 74(0): 663-681.

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The work of HRE

- Regional quantification
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    - Building heat demands
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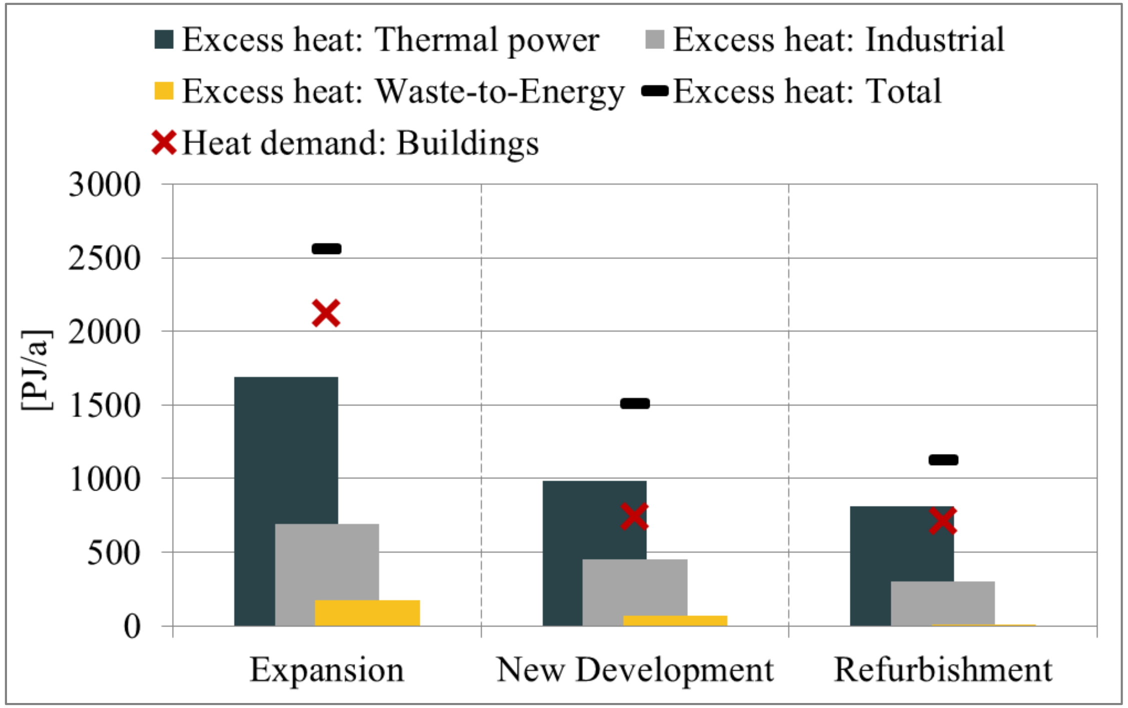
    - Towards allocation mapping…
    - Excess heat ratio
      - Excess heat by heat demands
    - Indicative
    - Member state categories by current district heating deployment levels



Category	Member States	NUTS3 regions [n]	DH integration level	Final analysis
Consolidation	DK, EE, FI, LT, LV, SE	72	Very high	Omitted
Expansion	AT, DE, FR, IT, SI	665	Medium	Included
New Development	BE, IE, LU, NL, UK	232	Low or medium	Included
Refurbishment	BG, CZ, HU, PL, RO, SK	178	Medium or high	Included
Out-of-scope	CY, EL, ES, MT, PT	134	No or low	Omitted

Source: Persson, U., Möller, B., Werner, S. (2014). Heat Roadmap Europe: Identifying strategic heat synergy regions. Energy Policy 74(0): 663-681.

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The work of HRE

- Allocation mapping

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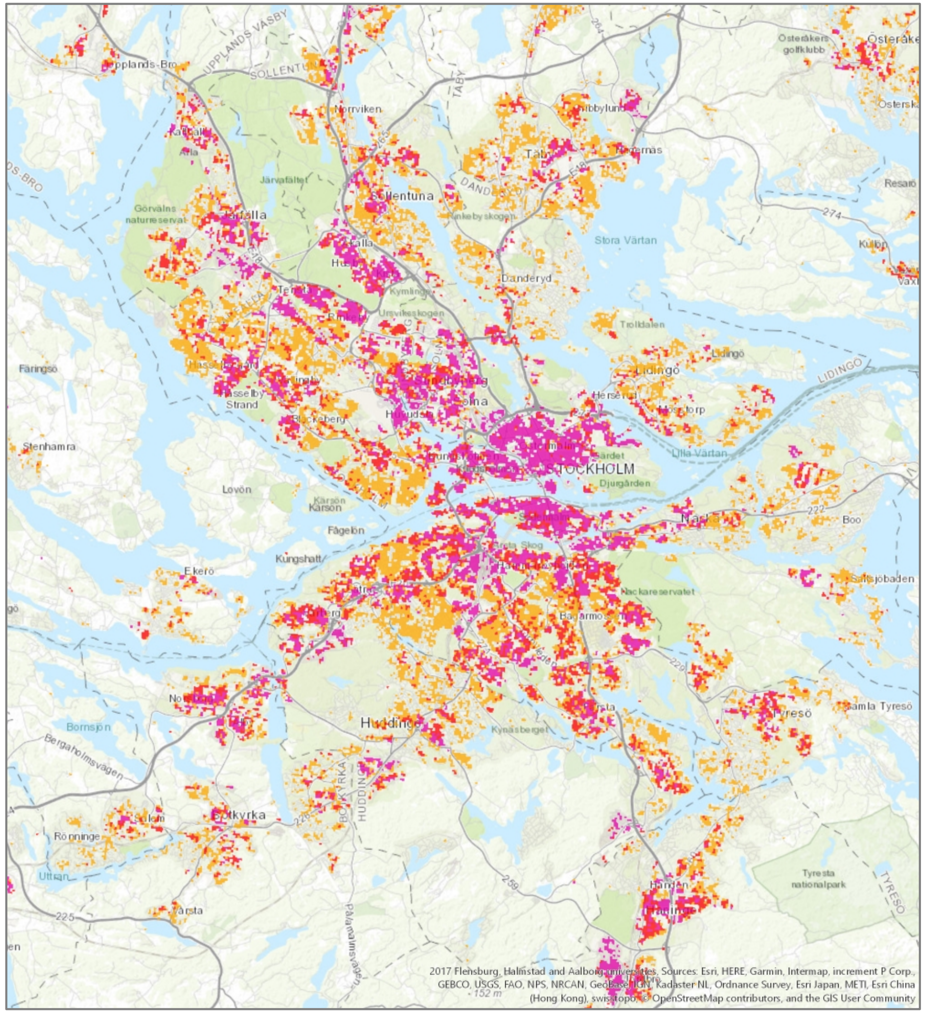
The work of HRE

- Allocation mapping
  - Demand and infrastructure
    - Heat demand densities



Source: Image print-out from the Pan-European Thermal Atlas (PETA 4.3), February 2019.

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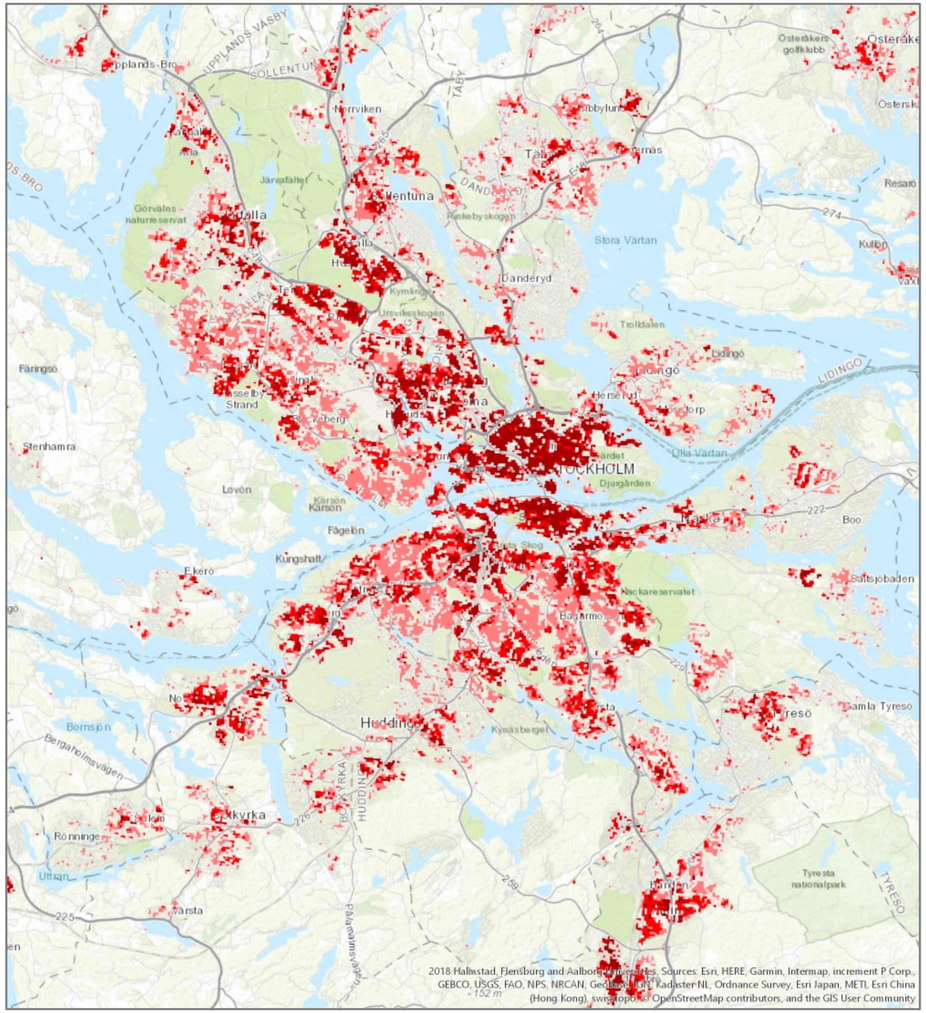
The work of HRE

- Allocation mapping
  - Demand and infrastructure
    - Heat demand densities
    - Heat distribution investment costs



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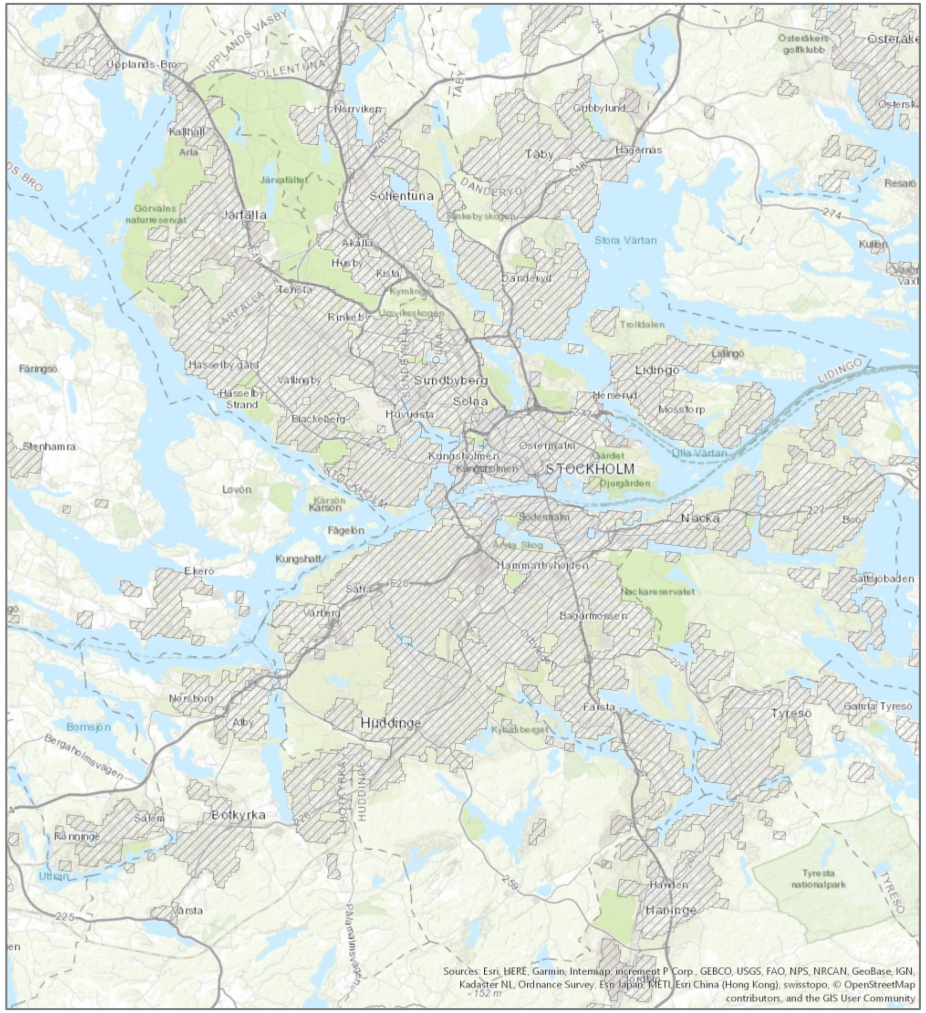
The work of HRE

- Allocation mapping
  - Demand and infrastructure
    - Heat demand densities
    - Heat distribution investment costs
    - Prospective Supply Districts (PSD)
      - Heat demand density above 20 TJ/km^2
      - ~50,000 in the 14 HRE4 MS



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  - Supply sources
    - Excess heat activities (Conventional)

Source: Image print-out from the Pan-European Thermal Atlas (PETA 4.3), February 2019.

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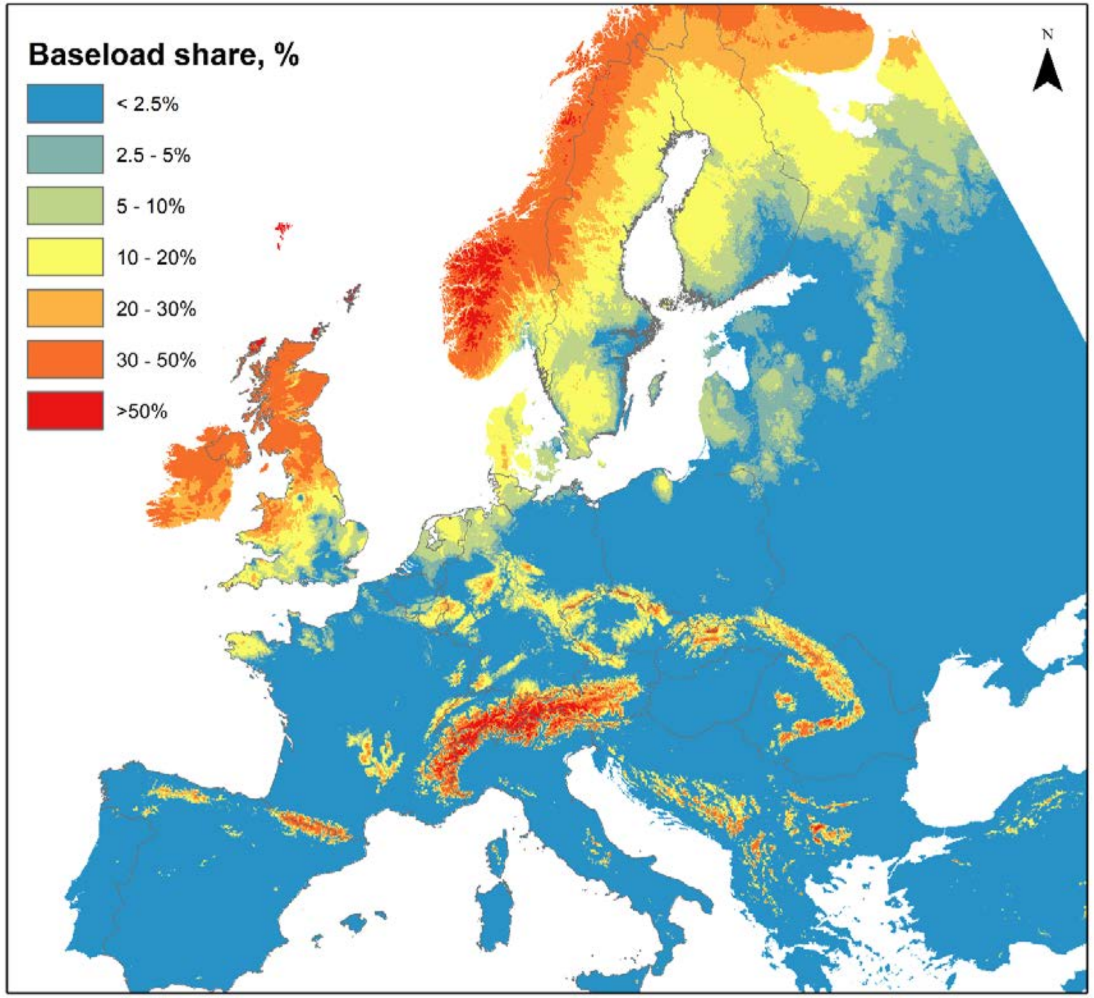
  - Supply sources
    - Excess heat activities (Conventional)
  - Spatial analytics
    - Baseload factor



Source: Möller B, Wiechers E, Persson U, Grundahl L, Søgaard Lund R, Vad Mathiesen B. Heat Roadmap Europe: Towards EU-Wide, Local Heat Supply Strategies. Submitted to Energy, December 2018. Under review.

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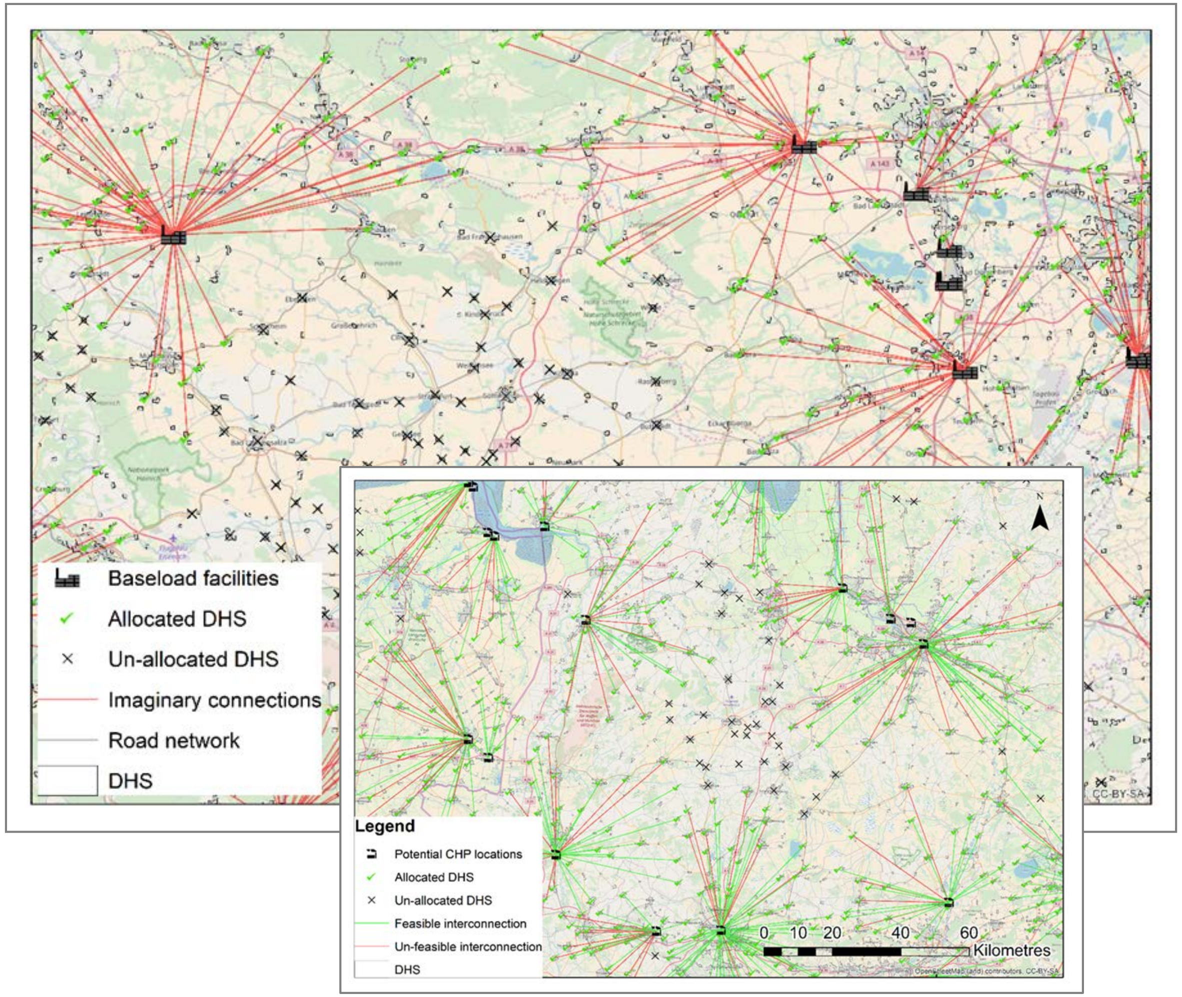
    - Excess heat activities (Conventional)
  - Spatial analytics
    - Baseload factor
    - Network allocation analyses (PSD)
      - Baseload supply (Industrial and WtE)
      - Seasonal load supply (Cogeneration)



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    - Baseload factor
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      - Baseload supply (Industrial and WtE)
      - Seasonal load supply (Cogeneration)

[PJ/a]	Heat demand (net)			District heat (net)	Excess heat (net)		Excess heat (gross)	
MS	Total	Urban	Rural	Urban	Baseload	Seasonal	Baseload	Seasonal
AT	232	177	55	122	9	70	12	96
BE	324	275	49	165	4	95	6	129
CZ	237	184	53	147	16	70	22	95
DE	2413	2089	325	1589	143	759	195	1035
ES	491	413	78	349	23	219	31	298
FI	226	176	50	126	3	109	4	149
FR	1563	1213	350	779	67	387	92	527
HU	209	177	32	82	3	41	4	56
IT	1285	1081	203	924	36	494	49	673
NL	426	376	50	276	18	98	24	134
PL	658	442	216	342	17	216	23	294
RO	183	117	66	81	3	52	4	71
SE	296	237	59	183	21	136	29	185
UK	1365	1198	167	630	62	155	85	212
HRE4	**9909**	**8154**	**1754**	**5798**	**425**	**2900**	**579**	**3954**

Note:
Additional allocation modelling for the 14 Member States has been performed in WP6 (national energy system modelling). Results presented in HRE4 country reports and Deliverable D6.4!

Source: Möller B, Wiechers E, Persson U, Grundahl L, Søgaard Lund R, Vad Mathiesen B. Heat Roadmap Europe: Towards EU-Wide, Local Heat Supply Strategies. Submitted to Energy, December 2018. Under review.

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Overview

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ReUseHeat – Extending the work of HRE

- Unconventional excess heat sources
  - Four source categories in the project
  - Excess heat temperatures below 50°C

Source	Recovery type	Temperature range	Temporality (diurnal)	Temporality (seasonal)	Heat pump conversion type
Data centres	Server room air cooling systems	25°C - 35°C	Principally constant	Principally constant	Air-to-Water
Metro stations	Platform ventilation exhaust air	5°C - 35°C	Variable	Variable	Air-to-Water
Service sector buildings	Central cooling devices	30°C - 40°C	Variable	Variable	Liquid-to-Water
Waste water treatment plants	Post-treatment sewage water	8°C - 15°C	Principally constant	Principally constant	Water-to-Water

Source: Persson U, Averfalk H. Accessible urban waste heat. Deliverable 1.4. ReUseHeat. Recovery of Urban Excess Heat. 2018.

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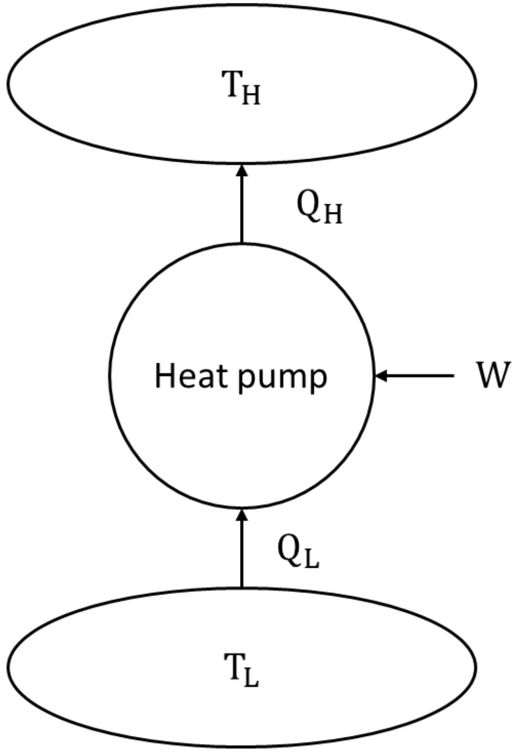
ReUseHeat – Extending the work of HRE

- Accessible and available excess heat
  - **Accessible** excess heat
    - Heat rejected from the condenser side of any given compressor heat pump
    - Sum of available excess heat and electric energy (W) introduced to the process
    - Equivalent to Q_H
  - **Available** excess heat
    - Heat available at a source and recoverable at the evaporator side of any given compressor heat pump
    - Equivalent to Q_L



Source: Persson U, Averfalk H. Accessible urban waste heat. Deliverable 1.4. ReUseHeat. Recovery of Urban Excess Heat. 2018.

Significance: By distinguishing between available and accessible excess heat, a vocabulary is given which recognises that the presence of an asset is something quite different from the marketing of a product.

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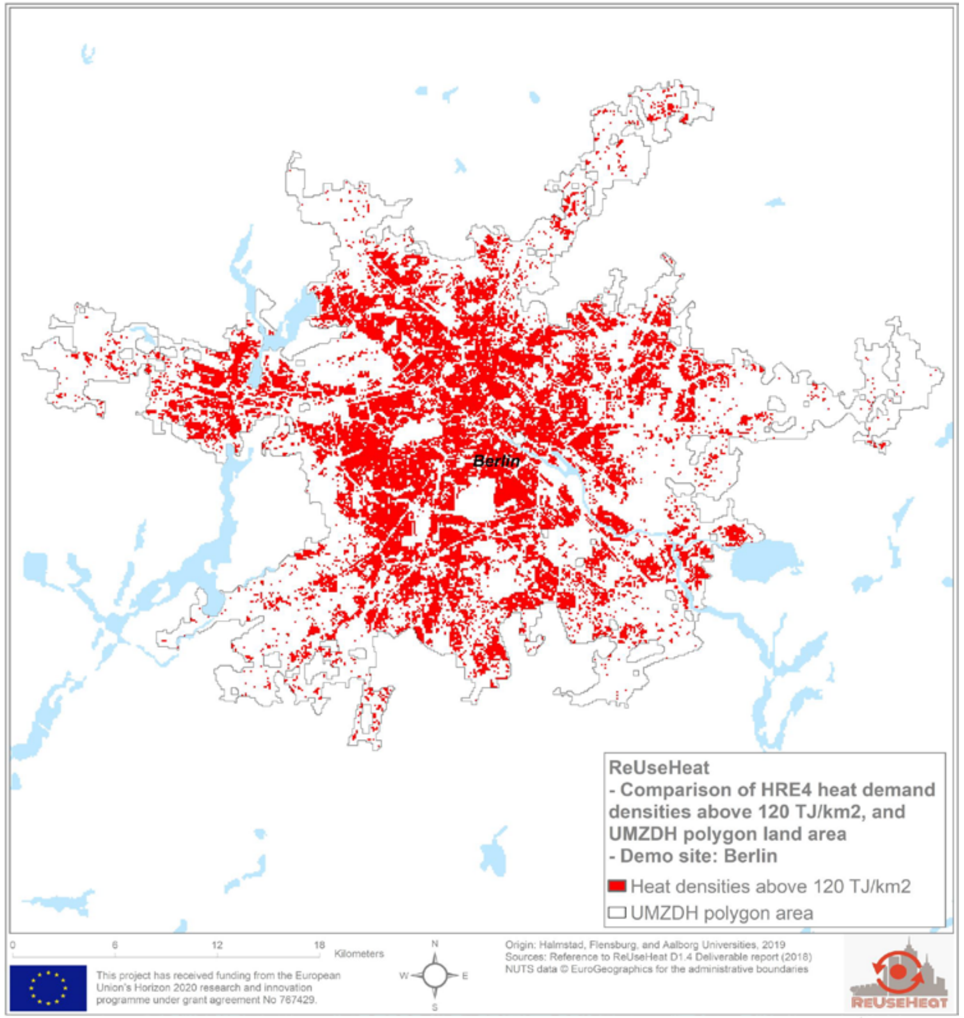
ReUseHeat – Extending the work of HRE

- Current district heating city areas
  - Spatial dimension (local conditions)
    - UMZ: Urban Morphological Zones
      - Clusters of urban settlements
    - Combined with district heating database
      - Current systems (EU28): ~4100
      - Current UMZDH areas (EU28): 3280
  - Spatial operation
    - Source distances to current UMZDH
      - Inside
      - 2 kilometres (default)
      - 5 kilometres
      - 10 kilometres
  - Potentials summarised for all settings



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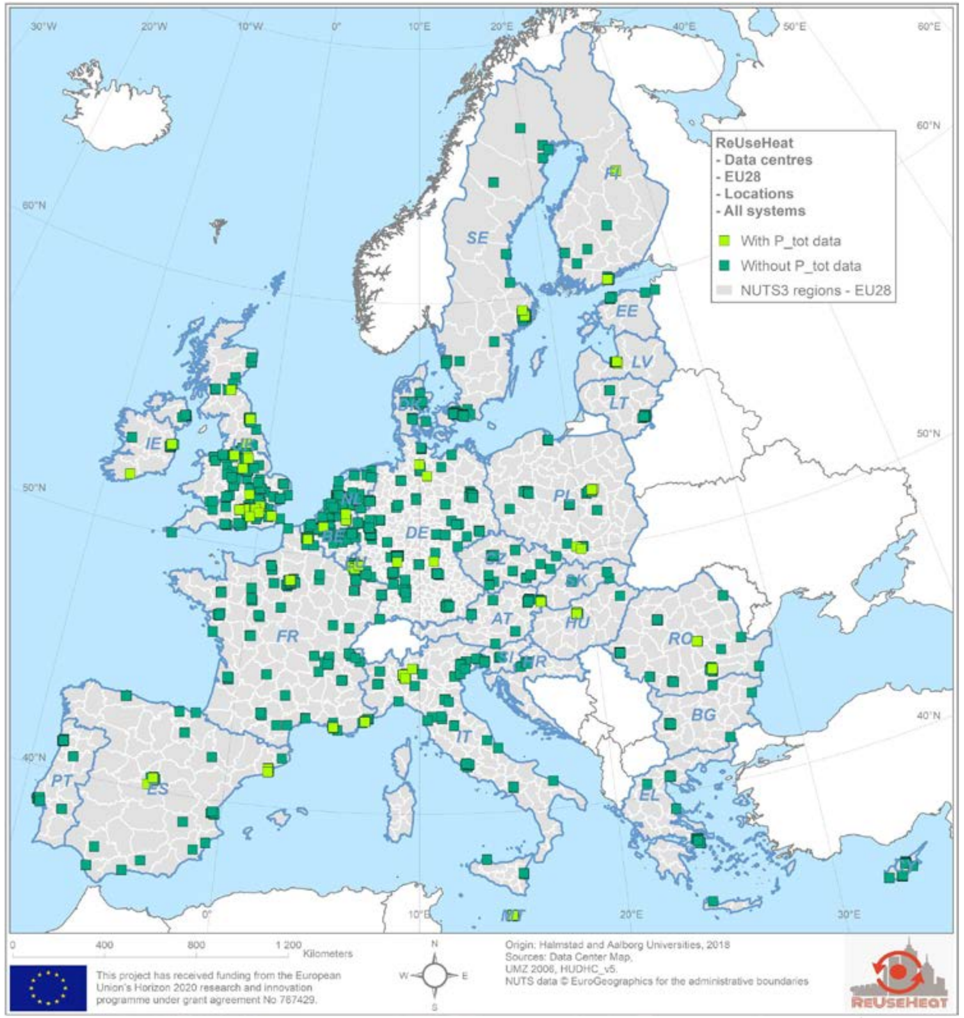
ReUseHeat – Extending the work of HRE

- Spatial allocation
  - Data centres
    - Average shares of electricity consumption (literature sources) combined with energy statistics
      - 65% of electricity consumption for IT-equipment assumed available (≈Q_L)
    - Geographical data on facility locations
      - World Data Center Map
        - ~1300 EU28 facilities
    - General sector confidentiality
    - Lack of quantitative data at site level
    - Spatial correlation to current district heating city areas
      - ~80% of centres located inside or within 2 kilometres of current district heating city areas!



Source: Persson U, Averfalk H. Accessible urban waste heat. Deliverable 1.4. ReUseHeat. Recovery of Urban Excess Heat. 2018.

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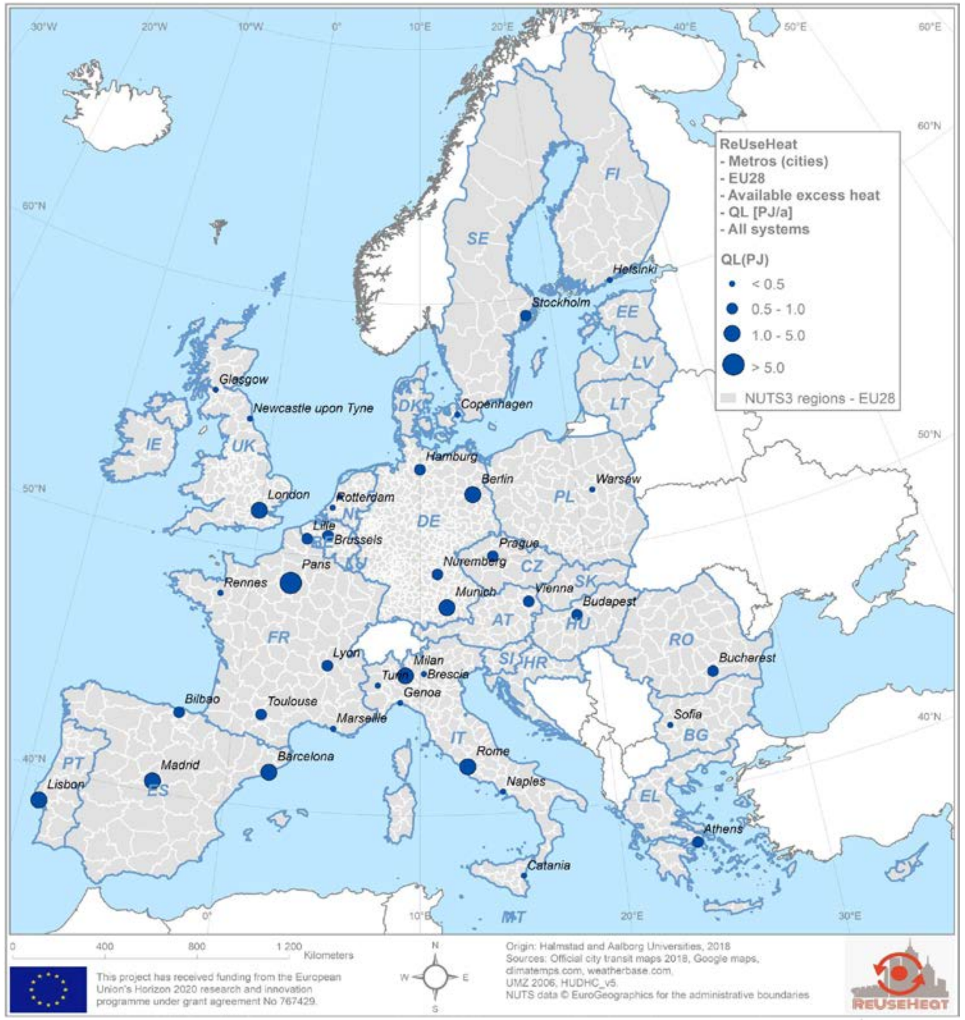
ReUseHeat – Extending the work of HRE

- Spatial allocation
  - Metro stations
    - Georeferencing of station locations
      - 37 cities operating heavy rail systems in EU28
      - +3000 stations in all
      - ~2000 metro stations
    - Literature studies
      - Station average air flows, capacities, relations etc.
    - Meteorological data
      - Monthly averages of temperatures and humidity
    - Sensible and latent heat
      - Cooling of exhaust air not below 5°C to avoid freezing on evaporator walls
    - Spatial correlation to current district heating areas
      - 31 cities with district heating systems
      - 1860 underground stations



Source: Persson U, Averfalk H. Accessible urban waste heat. Deliverable 1.4. ReUseHeat. Recovery of Urban Excess Heat. 2018.

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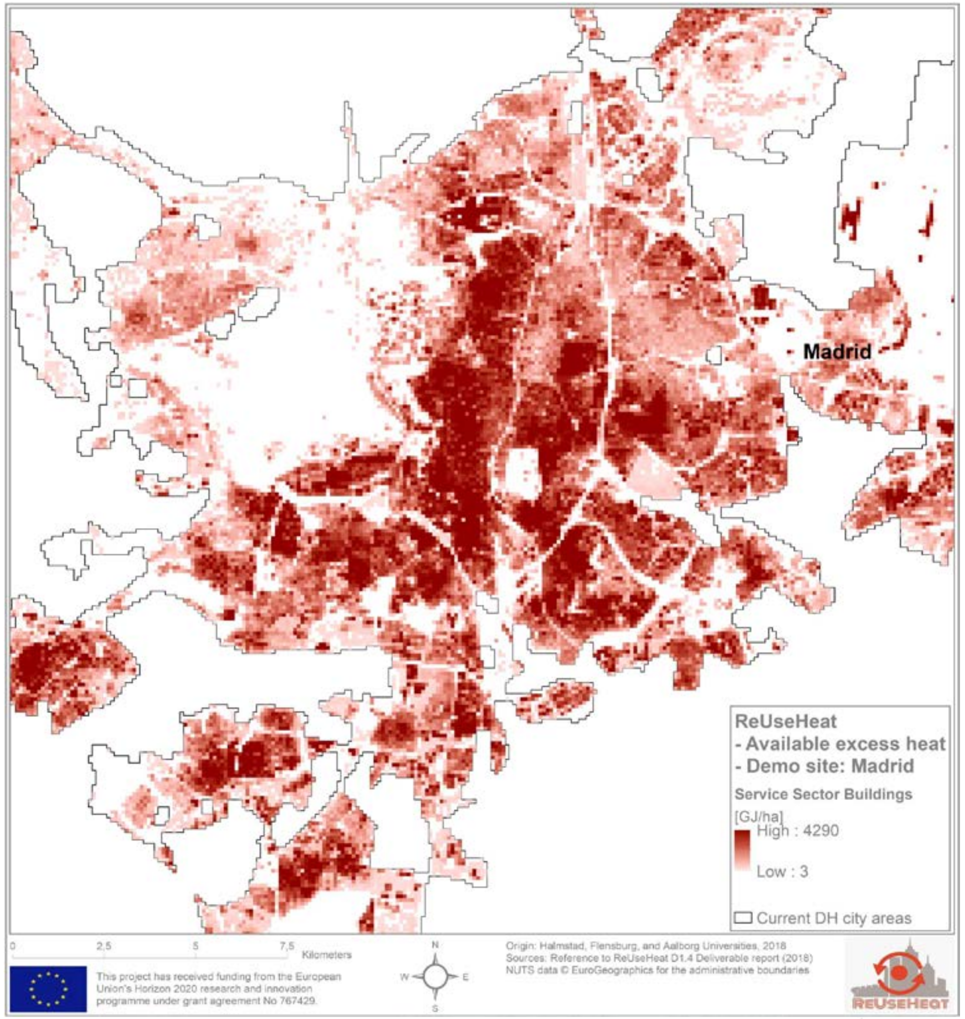
ReUseHeat – Extending the work of HRE

- Spatial allocation
  - Service sector buildings
    - Data on service sector floor areas
      - Hotmaps: “gfa_nonres_curr_density” dataset
        - Spatial data by hectare resolution
    - Cooling demand data by member states
      - HRE4, WP3
        - Specific cooling demands
        - Shares of cooled areas (saturation rates)
    - Seasonal energy efficiency ratio
    - Raster calculations
    - High sensitivity to temporal dimension
    - Spatial correlation to current district heating city areas
      - Inside



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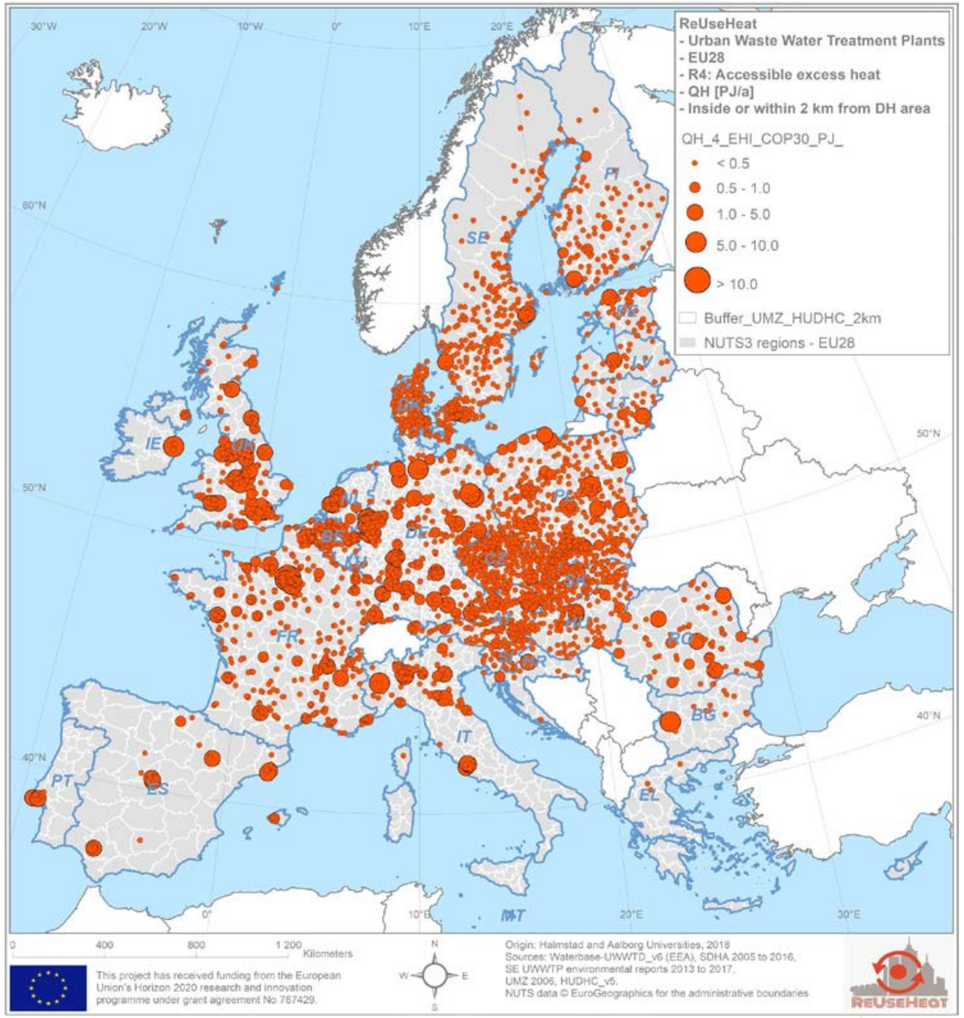
ReUseHeat – Extending the work of HRE

- Spatial allocation
  - Waste water treatment plants
    - Best-fit linear regression function from a reference model applied to facilities recorded in the EEA database:
      - Reference model
        - Time-series data from 20 Swedish district heating operators and corresponding sewage facilities
      - Waterbase-UWWTD_v6 dataset (EEA)
        - Plant capacities
        - Site coordinates
    - Adjustment to seasonality of heat demands
    - Spatial correlation to current district heating city areas



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ReUseHeat – Extending the work of HRE

- Spatial allocation
  - Data centres
    - Top-down assessment
  - Metro stations
    - Station values by city averages since no data on unique station traffic intensities
  - Service sector buildings
    - Shares of cooled floor areas applied uniformly
  - Waste water plants
    - Conservative assessment since based on lowest projection towards benchmark level

	All facilities			2 kilometres of UMZHD		
[PJ/a]	Number	QL	QH (COP 3.0)	Number	QL	QH (COP 3.0)
Data Centres	1269	228	342	997	180	271
Metro Stations	1994	35	53	1854	32	49
Service Sector Buildings	-	536	804	-	194	292
Waste water treatment plants	23189	763	1144	3982	417	625
Total	**26452**	**1563**	**2344**	**6833**	**824**	**1236**
Share				26%	53%	53%

Note:
Additional allocation modelling for the demo site Member States is currently being performed in Task 1.3 (national energy system modelling) and Task 1.4 (demo cities modelling).
Results to be found in ReUseHeat Deliverables D1.5 and D1.6!

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Overview

- Excess heat potentials
  - The work of HRE
    - Conventional excess heat sources
    - Regional quantification
    - Allocation mapping
  - ReUseHeat – Extending the work of HRE
    - Unconventional excess heat sources
    - Accessible and available excess heat
    - Current district heating city areas
    - Spatial allocation
  - Results and conclusions
    - Potentials summary
    - Challenges and drivers
    - Recommendations

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Results and conclusions

- Potentials summary
  - Conventional sources
    - Maximum theoretical potentials
      - Default recovery efficiencies
    - Regional potentials
      - Quantification by NUTS3 regions
    - Prospective supply districts (PSD) potentials
      - Allocation by baseload and seasonal load
  - Unconventional sources
    - Accessible potential (usable heat)
      - Output from large-scale heat pumps
    - Available potential (resource heat)
      - Input to large-scale heat pumps or other recovery technologies

Mapped EU28 potential:
Conventional (PSD):
Baseload (Industrial & WtE): 579 PJ/a
Seasonal (Cogeneration): 3954 PJ/a
Unconventional (Available):
Inside or 2 km from DH area: 824 PJ/a

Current use:
Conventional (Heat output):
Cogeneration: 1654 PJ/a (IEA, 2014)
of which: Waste-to-Energy: ~170 PJ/a
Industrial: ? (~25 PJ in 2008)
Unconventional (Available):
Inside or 2 km from DH area: ?

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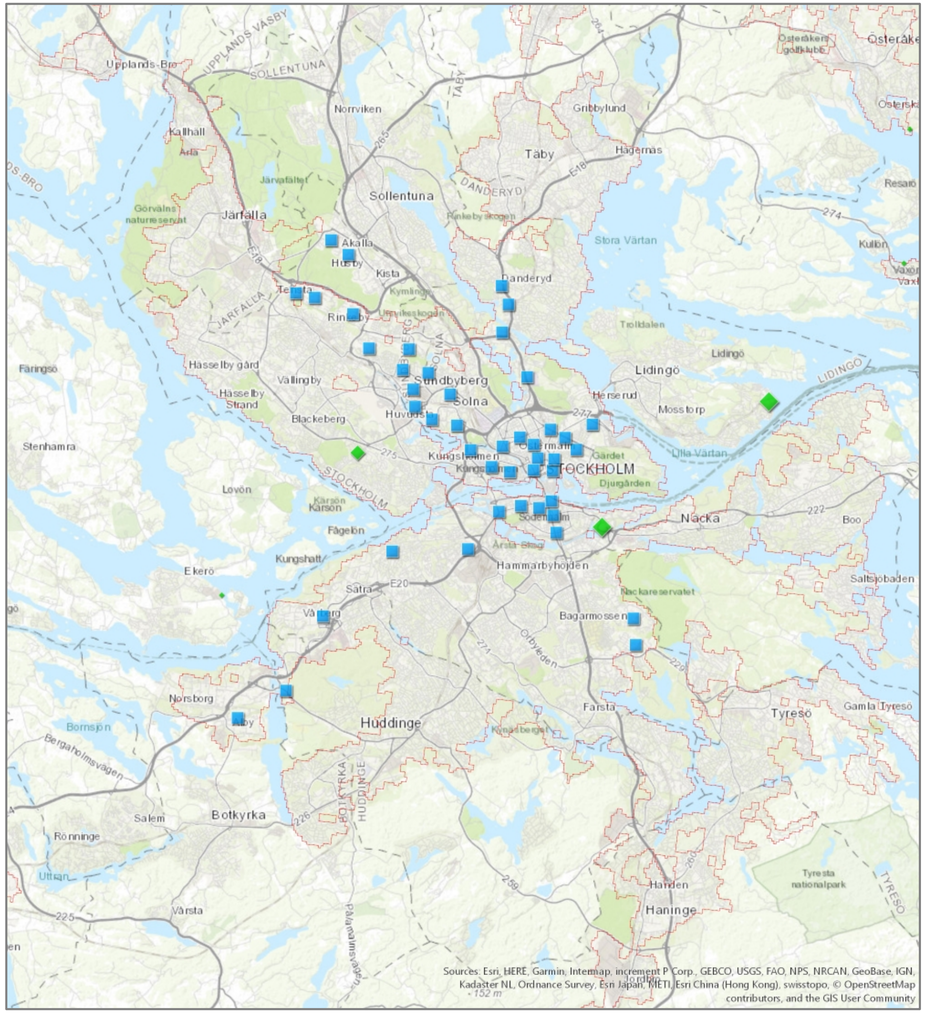
Results and conclusions

- Challenges and drivers
  - Challenges
    - Invisibility
    - Complexity
    - World market energy prices
      - Exposure to electricity prices
    - Infrastructure investments
      - Heat distribution & heat pumps
    - Multiple business objectives
  - Drivers
    - High heat densities in inner city areas
    - New business models and practises
    - Consumer choices in heat distribution
      - Demand-driven utilisation



Source: Image print-out from the Pan-European Thermal Atlas (PETA 4.3), February 2019.

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Results and conclusions

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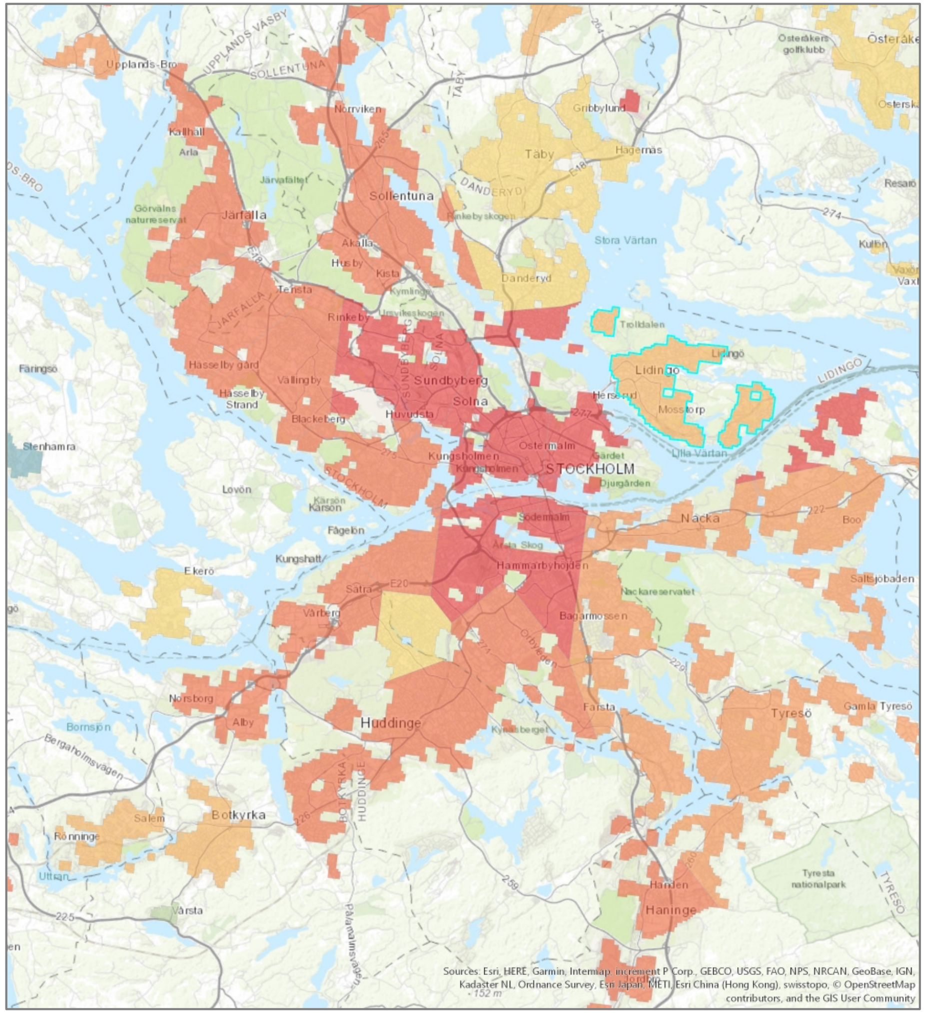

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Results and conclusions

- Recommendations
  - Modelling and mapping tools – Yes!
    - But calls for dedicated cooperation across sectors!
  - Regional energy planning
    - Informed decision-making involving all actors
  - Allocation of synergy benefits
    - A good deal for all involved!
  - A transition from parallel to serial supply structures can:
    - Build on existing technologies
    - But exceeds pure technical dimensions…

> *“Injure no one; on the contrary, help everyone as much as you can.”*
>
> A. Schopenhauer (1840), On the Basis of Morality.

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Thank you!

Questions?

Dr. Urban Persson
urban.persson@hh.se
School of Business, Engineering and Science
Halmstad University, SWEDEN

See also:
ReUseHeat: http://reuseheat.eu
Heat Roadmap Europe: http://heatroadmap.eu
Pan-European Thermal Atlas: https://heatroadmap.eu/peta4/

ReUseHeat Online Survey:
Gathers experiences from existing unconventional excess heat recovery projects.
Participate at: https://www.reuseheat.eu/collecting-information-urban-excess-heat-sources/

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